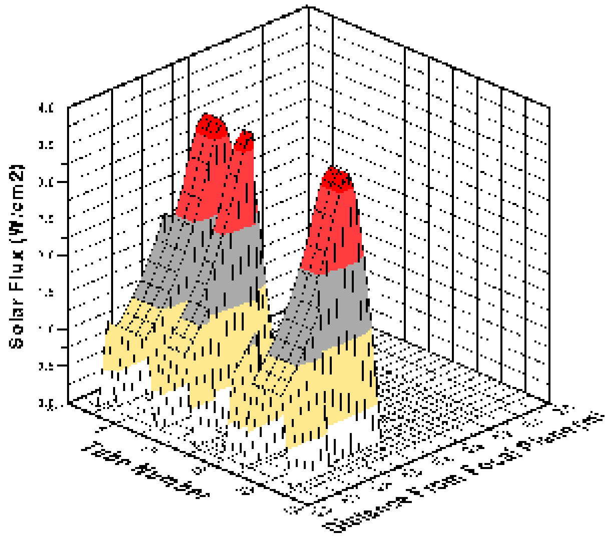
Analysis of Solar Receiver Flux Distributions for U.S./Russian Solar Dynamic System Demonstration on the MIR Space Station

Analyses have been performed at the NASA Lewis Research Center's Power Systems Project Office to support the design and development of the joint U.S./Russian Solar Dynamic Flight Demonstration Project. The optical analysis of the concentrator and solar flux predictions on target receiver surfaces have an important influence on receiver design and control of the Brayton engine.

The MIR spacecraft is a complex collection of solar arrays and pressurized modules. The solar dynamic module is planned to be attached to one of the pressurized modules currently in orbit. The mirror on the solar dynamic module has 36 individually deployable reflective petals that form an on-axis paraboloid. with a 9.5-m outer diameter. A cylindrical, cavity-type heat receiver is located at the concentrator focal plane (see ref. 4 for a complete description). Its cavity is lined with heat exchanger tubes that store thermal energy and heat the working fluid. Concentrated solar energy enters this cavity via an aperture that is centered at one of its ends. Energy not intercepted by the aperture is deposited on an aperture shield. Before full-scale development begins, the receiver and aperture shield designs must undergo a stress analysis, which is mainly a function of the energy distribution, to assure the reliability and functionality of the solar dynamic module.

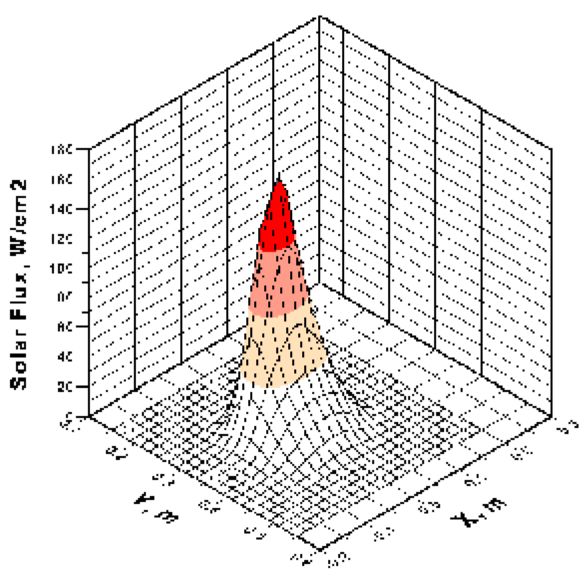
To enable this receiver thermal stress analysis, solar flux distributions had to be calculated for the receiver cavity and aperture shield. Analyses were conducted to determine these distributions, accounting for a finite Sun size with limb darkening, concentrator surface slope and position errors, concentrator petal thermal deformation, gaps between petals, and the shading effect of the receiver support struts. The optical analyses were performed using CIRCE2 (see ref. 3). Then, the receiver spatial flux distributions were combined with concentrator shadowing predictions from software developed by NASA Lewis (see ref. 1). Geometric shadowing patterns were traced from the concentrator to the target receiver surfaces. These patterns vary with time depending on the chosen MIR flight attitude and the orbital mechanics of the MIR spacecraft. The resulting predictions provide spatial and temporal receiver flux distributions for any specified mission profile.



Receiver cavity shadowed flux.

The preceding figure shows a typical flux distribution for a time step during the sunlit portion of the orbit. Shadowing causes wide variations in the solar flux, and thus in temperatures, for adjacent tubes. When shadowing is transient in nature, because of the receiver canister thermal mass, the tube temperatures are reduced. However, when shadow patterns are constant, higher stresses are inevitable.

The following figure shows a nongaussian aperture plane flux distribution with a 4.5° concentrator pointing error. For certain MIR or solar dynamic system emergencies, the concentrator will be off-pointed and maintained at the 4.5° error until complete concentrator off-pointing can take place during orbit eclipse. These relatively high flux levels, which occur infrequently, must be accommodated by the design of the aperture plate.



Nongaussian aperture plane flux distribution with 4.5° pointing error.

Additional information can be obtained from the author or reference 4.

References

1. Fincannon, J.: Analysis of Shadowing Effects on MIR Photovoltaic and Solar Dynamic Power Systems. NASA TM-106940, 1995.

2. Kerslake, T.W.; and Fincannon, J.: Analysis of Solar Receiver Flux Distributions for US/Russian Solar Dynamic System Demonstration on the MIR Space Station. NASA TM-106933, 1995.

3. Romero, V.J.: CIRCE2/DEKGEN2: A Software Package for Facilitated Optical Analysis of 3-D Distributed Solar Energy Concentrators. SAND-91-2238, Sandia National Labs, Albuquerque, New Mexico, 1991.

4. Strumpf, H.J.; Krystkowiak, C.; and Klucher, B.A.: Design of the Heat Receiver for the U.S./Russia Solar Dynamic Power Joint Flight Demonstration. Proceedings, 30th Intersociety Energy Conversion Engineering Conference, IECEC Paper AP-168, ASME, 1995, p. 411.